Orbital Debris Radar Instrumentation

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In order to increase the usefulness of Goldstone orbital debris observations, several improvements are planned to the experimental Goldstone radar. The first improvement is to add a ranging capability of 1-km accuracy to the radar. This would provide much more detailed information about whatever debris is observed. The second improvement is to widen the bandwidth of the system from 10 kHz to 85 kHz so that particles in more elliptical orbits can be monitored. The two antennas could then also be pointed away from the zenith, say south, where orbits of lesser inclination might also be observed. In any case, the addition of ranging requires a substantial increase of system bandwidth. This article describes the instrumentation necessary to achieve this, together with required signal-processing modifications.

I. Introduction

Orbital debris has been recognized as a rapidly increasing hazard for United States and world activities in space. Individual pieces of debris larger than about 10 centimeters are now routinely tracked and catalogued by the Space Surveillance Network, operated by the Department of Defense [1]. Research in debris population modelling and shielding is being done at the National Aeronautics and Space Administration's (NASA's) Johnson Space Center [2]. In addition, Space Station planners have included enough shielding in their design to withstand impacts with one-centimeter and smaller sized objects. However, orbiting particles even below one millimeter in size can be lethal to an astronaut working outside of this protective shielding.

In an attempt to assess the magnitude of this hazard, two preliminary radar experiments have been performed: one at the Arecibo Observatory [3] and the other at Goldstone [4]. The results gave an irregular detection rate of about two events per hour. This corresponds to a particle flux of 6.4 objects per square km per day of equivalent size of 1.8 mm or greater.

Only a small amount of orbital parameter space was monitored by these experiments. For the Goldstone experiments, the particles were illuminated at X-band (8.5 GHz) by the transmitter and antenna at Deep Space Station (DSS) 14; the receiver was at DSS 13, 21.6 km away. The two antennas were aimed at a point midway between them, and 600 km above ground level. The intersection of the two beams spanned an altitude difference of only 40 km. Due to bandwidth limitations of the radar system, only particles with near circular orbits could be observed. Any debris moving with a radial velocity greater than 88 m/sec would be Doppler-shifted outside of the receiver bandwidth.

II. Instrumentation Improvements

In order to increase the usefulness of Goldstone orbital debris observations, several improvements are planned to the experimental Goldstone radar. The first improvement is to add a ranging capability of 1-km accuracy to the radar. This would provide much more detailed information about whatever debris is observed. The second improvement is to widen the bandwidth of the system from 10 kHz to 85 kHz so that particles in more elliptical orbits can be monitored. The two antennas could then also be pointed away from the zenith, say south, where orbits of lesser inclination might also be observed. In any case, the addition of ranging requires a substantial increase of system bandwidth. The third improvement involves more efficient signal processing. The system is able to perform the bulk of the processing on line, simultaneously with the observations, so that at the end of a track the data are already reduced and recorded. Thus, transporting the many rolls of magnetic tape, and the long, overnight computer runs of the earlier Goldstone experiment will no longer be necessary.

III. System Design

Ranging systems in the Deep Space Network (DSN) have always required accurate knowledge of the range rate. In the case of orbital debris, however, such information is not available. Particles can be expected to intersect the beams with considerable variation of radial velocities. Weak signal detection requires a separate correlation for each range-Doppler cell of interest, a prohibitive work load for the usual pseudonoise modulation system.

The design uses, instead, a chirp signal, which can search out a linear combination of range-Doppler cells simultaneously. Since, at most, one object is expected to be in the beam at a time, alternate use of up- and down-chirps enables the estimation of both range and Doppler.

Transmission will be a linear chirp (up or down) of 50-kHz bandwidth and 2-msec duration; 6 msec of receive time will follow. The typical particle of debris will remain within the DSS 14 beam for about six of these eight millisecond cycles.

Reception consists of the digitization of the received signals at a rate of 85 kHz (both in-phase and quadrature), the convolution of the samples with the appropriate reference, and the summation of squared magnitudes for each set of six send–receive cycles. These calculations are to be done in real time, in parallel with the signal sampling. When any result of the above calculations exceeds a preset threshold, those data are saved for additional analysis. In this way, only the "interesting" results from an entire radar pass need to be considered further, and are saved on the computer floppy disk.

IV. Hardware

The system described above has been implemented on a standard personal computer (PC) clone with an AT bus and an Intel 386 processor. Plugged into one of the expansion slots of the PC is a signal-processing board purchased from the Spectrum Signal Processing Company. This board contains an AT&T DSP32C processor, capable of 25 million floating point operations per second; 32 kbytes of high-speed memory and 128 kbytes of somewhat slower memory; an analog interface consisting of a timer, two Burr-Brown analog-to-digital and two digital-to-analog converters capable of a maximum speed of 100,000 samples per second each; an interface to the host PC that supports both direct memory access to the DSP32C and interrupts to the PC; and a high-speed serial and parallel input/output port.

This board handles digitization of the received signals, generation of the transmitted waveform, and signal processing required for orbital debris detection. Most of the computations are done on the DSP32C, which can perform a 512-point complex fast Fourier transform in 1.6 msec. The host PC performs the file keeping and display functions.

V. Software

The host computer is programmed in Microsoft C. Several C-callable routines are used to upload and download data and programs between the host computer and the DSP32C processor. In addition, much use has been made of a debugging routine for the assembly language of the DSP32C. These routines were written by the Loughborough Company and were supplied with the signal-processing board.

Programs for the DSP32C were written on the host computer in assembly language, with the aid of an AT&T assembler–linker package. A C compiler was provided with the DSP32C, but the resultant code was both too long and too slow.

Several programs have been written for the system, each with one part in C for the host computer and a second part in assembly language for the DSP32C processor. The first program is the operational program, which implements the radar system functions, has a display for the operators, and reduces the data to a floppy disk at the conclusion of a track. In addition, there are test programs to ensure that actual signals of the correct level are applied, and that the transmitter and receiver can operate in harmony in a closed loop.

VI. Configuration for Experiments

The above-described hardware and software are now installed at DSS 14. When antenna time for the radar becomes available, the new system will be tested using the DSS-14–DSS-13 combination as in the previous experiments. If at all possible, the receiver will be located at DSS 15. With DSS 14 transmitting and DSS 15 receiving, the beam intersection would form a column extending from about 200 km outward. Thus, altitudes from 200 km to 1000 km could be monitored instead of only the 40-km thick area that is presently available with the DSS-14–DSS-13 combination, resulting in much more efficient use of DSN antenna time for monitoring orbital debris.

References

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